Validating Arterial Spin Labeling Cerebral Blood Flow measure with perfusion phantom

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Introduction & Motivation

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- Arterial Spin Labeling (ASL) used to assess Cerebral Blood Flow (CBF)
- “white paper” with recommendations [1] for optimal acquisition.
- High repeatability, high reproducibility and high reliability desired.
- CBF measure may still have large inter- and intra-subject variability, however.
- CBF to be used as surrogate for physiological features ?
- Separate different signal components contributing to the ASL signal would be possible in controlled conditions when using a physical model of the cerebrovascular geometry (e.g. phantom) without subject-related variance.

Solution: -A phantom that simulates cerebral blood flow.
-A phantom that allows systematic changes of a limited and controlled set of ASL parameters.

Cross-check validation of CBF measure: Transparent perfusion-phantom. Independent “optical based” CBF assessment. Injection of a bolus of dye at the location of the ‘carotid artery’. 3D-CCD cameras will capture signal. Measure of the integral of the local dye concentrations along the line of sight.

ASL and Pump tuning parameters

ASL parameters:
We have systematically changed a reduced set of ASL parameters [2, 3, 4] that may potentially influence the ASL signal.

- Post-labeling delay [ms]: 300:300:2700;
- Bolus duration: #RF:20, 60, 80;
- Bolus duration: #gap between RF [ms]: 0.36, 0.54, 0.9;
- Bandwidth [Hz/Pixel]: 752, 1264;
- Distance label-plane to Isocenter: 5:1:12 [cm]
- Matrix dimension: 64x64, 128x128;
- Flow Volume*Flow Rate [ml/min]: 20:20:200;
- Flow Ratio: 0.5, 1, 1.5.

Pump: Harvard Apparatus Pulsatile Blood pump for hemodynamic studies. Valve and shunts to be placed in the circuit to regulate the pressure and flow in the perfusion-phantom. Flow-meter will control the flow at the input/output tube.

Phantom details and Phantom in operation mode

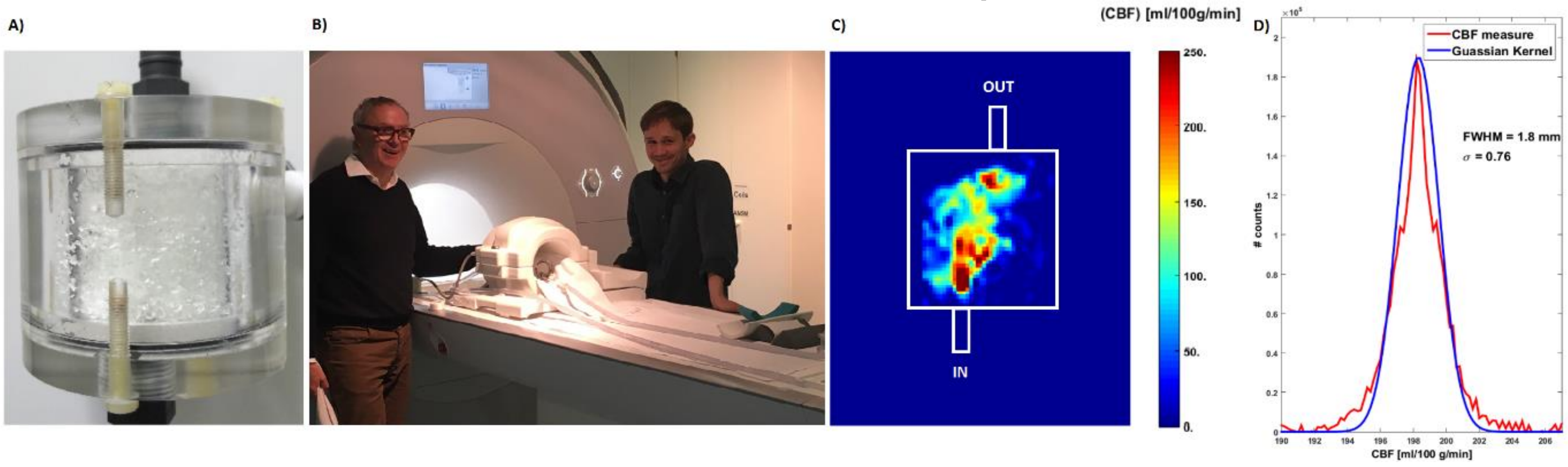

Figure 1. **A)** The ASL phantom in MRI setup. **B)** The perfusion phantom in the MR setting with the PVC tubes attached within the receiver coils. **C)** Axial view of estimated CBF maps in the middle of the ASL phantom. The color bar indicates the range of CBF values. **D)** Histogram of measured CBF values. The measured CBF values correspond to the setting of the ASL sequence and the setting of the pulsatile pump. The accuracy of the estimated CBF values can be extracted from FWHM as shown in the figure. The distribution of the corresponding fitted Gaussian Kernel shows precise fit for SD=0.76.

Results: The perfusion phantom is operating (Fig 1.A and B). Due to the large amount of different sequence and pump settings we present a limited set only. Setting the pump Flow volume*Flow rate at 200 [ml/min], a flow ratio of 1, post labeling delay of 500 ms revealed an extraordinary high precision of CBF estimation by the perfusion phantom: 198.3029 ± 0.76 [ml/100g/min] (Fig 1.C and D).
The signal to noise ratio (SNR) was 4.2. The expected value of CBF was therefore underestimated by 1.7 [ml/100g/min].
The error in CBF estimation is 0.5 % which is at same level as the accuracy of the pulsatile pump.

Discussion & Outlook:

A perfusion phantom was constructed and is working with 125 cm3 volume filled with SiO_2 spheres of different diameters [e.g. 0.01 mm 0.05 mm and 0.1 mm]. Due to this set of diameters an average pore size of 0.0138 mm was achieved: which is a factor 2 larger than average diameter of capillaries of ~ 6 μm (Fig. 1 A).

The perfusion phantom with the pulsatile pump showed high accuracy of CBF estimation that was reliable and reproducible. The observed CBF values showed high precision (i.e. low standard deviation) that allows to draw conclusion about the variance of the CBF measure originated by the ASL sequence only.

Uncertainty in CBF estimation by ASL technique may therefore be assessed [5]. This novel approach will finally allow clinicians, physicians and researchers to unambiguously estimate disease-related CBF effects [5]. Therefore, it is relevant for patients as well as for socioeconomic aspects. The perfusion phantom will be generalized to be used at other institutions to enable quality controls on different scanners with different ASL sequences and different field strengths: since the phantom is stable and easy to send.

The present phantom will be tuned with smaller SiO_2 spheres in order to reach the average diameters of capillaries.

References:

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